

§8. Scaling Law in Collisionless Driven Reconnection

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Particle simulation studies[1] show that collisionless driven reconnection develops in two steps in accordance with the formation of two current layers, i.e., ion current layer in which the ion kinetic effect becomes dominant, and electron current layer which is created inside the ion current layer and has a fine spatial structure characterized by an electron kinetic scale. From the particle simulation runs with different values of ion mass m_i , electron mass m_e and driving electric field E_0 , it is found that the evolution time scales as $E_0^{-1/2} m_i^{1/4}$, and depends little on the electron mass. Figure 1 shows one example of simulation runs where the dependence on the ion mass is examined. We find in Fig. 1 that the evolution time scales as $M_i^{1/4}$.

This scaling law can be explained as follows. Both ions and electrons are magnetized outside the ion current layer, while ions are unmagnetized and electrons are magnetized inside the ion current layer. A convergent plasma flow carries the magnetic field from the system boundary towards the ion current layer and compresses it. Since magnetized drifting electrons can penetrate through the ion current layer, magnetic flux can be carried inside. Thus, the ion current layer dynamically evolves while satisfying the balance between the plasma compression by the convergent plasma flow and the penetration of the magnetic flux into the ion current layer. This balance equation gives rise to $E_0/B \propto E_0^{1/2} m_i^{-1/4}$, which explains the scaling law of collisionless driven reconnection. It is concluded that collisionless reconnection is controlled by the ion dynamics of the current layer.

Based on the finite correlation time of the particle's velocity vector in strongly varying magnetic fields, Horton and Tajima[2] have derived the collisionless conductivity as

$$\sigma^i = c_0 \frac{n_0 e}{B} \left(\frac{\rho_i}{L} \right)^{1/2}, \quad (1)$$

where c_0 is a constant and L is the scale height of magnetic field. We apply this formula to Ampère's law at the edge of ion current layer and get the relation as

$$\frac{B}{(4\pi n_0 m_i)^{1/2}} = c_0 \frac{c E_0}{B}, \quad (2)$$

where the width of ion current layer is given by the ion meandering scale $l_{mi} = (\rho_i L)^{1/2}$, and the pressure balance equation $p_i = n_0 T_i = B^2/(8\pi)$ is used. Equation (2) gives rise to the same scaling law as the simulation result, i.e., $E_0/B \propto E_0^{1/2} m_i^{-1/4}$ [3]. This agreement suggests that an anomalous resistivity associated with the stochasticity of ion orbit in the current layer may be a cause of collisionless reconnection even for the system which is subject to the external driving flow.

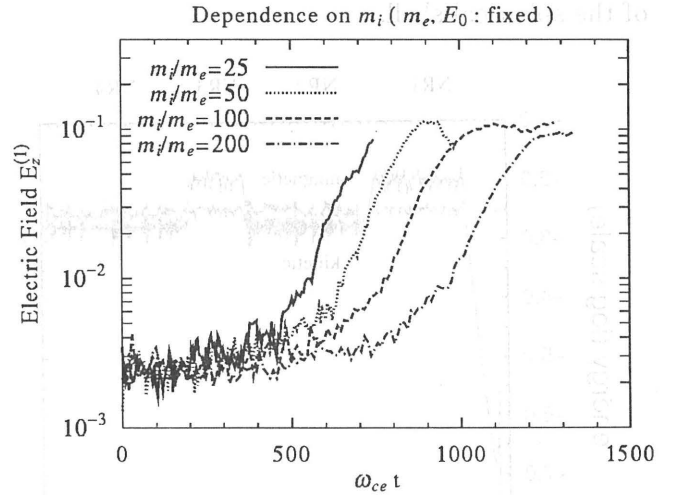


Figure 1: Temporal evolutions of the reconnection electric field for four different ion masses.

References

- 1) R. Horiuchi and T. Sato, Phys. Plasmas **1**, 3587(1994): **4**, 277(1997).
- 2) W. Horton and T. Tajima, J. Geophys. Res. **96**, 15811(1991).
- 3) R. Horiuchi, T. Sato, and W. Horton, Bulletin of A.P.S., **42**, 1886(1997).